VOLUME 35 DECEMBER 1951 NUMBER 12

NBS Model Antenna Range

THE National Bureau of Standards has recently completed a new model antenna range to facilitate the measurement of antenna radiation patterns in the vertical plane. The range is believed to be the largest ever designed for this purpose. It is composed of an inverted V-type structure, which supports a test or target transmitter more than 50 feet above a ground plane, in the center of which is placed the model antenna to be tested. The model techniques employed in this type of installation are being applied to an NBS investigation of the behavior of high-frequency antenna systems used in ionosphere-sounding equipment. The range was designed and built under the supervision of H. V. Cottony at the NBS Radio Propagation Station in Sterling, Va.

The NBS antenna investigations are particularly concerned with the high-frequency band from 3 to 30 Mc, in which the major portion of long-distance communication is carried on. At these frequencies the wavelength varies between 300 and 30 feet; consequently measurements of full-sized antennas would require a site several thousand feet long. This presents a problem when merely ground plane radiation patterns are desired; but, when the pattern in a vertical plane is required, the problem becomes even more complex. Some investigators have utilized free-flight balloons and aircraft to carry the test, or target, transmitter aloft, but the results have been only partially satisfactory. The NBS model antenna range was set up to provide a more reliable means for such studies. It has been found that model techniques offer a promising approach for the analysis of antenna problems.

The model techniques employed in NBS antenna studies are similar in many ways to those used in the investigation of mechanical, hydraulic, and aerodynamic structures. The principle is known as electrodynamic similitude. As applied to an antenna, an equivalent performance is obtained from a model $1/n$-th as large as the prototype antenna if its operating frequency is made n times the prototype frequency. As the model frequency is increased, the free-space wavelength is decreased proportionately, and the distance between the transmitting and the receiving antennas can be then reduced by the same scaling factor, n. Thus it becomes possible, by using a sufficiently large scaling factor, to mount a target transmitter on a rigid structure, to move it over and about the model antenna under test, and to obtain radiation patterns substantially the same as the true long-distance radiation patterns of a full-scale antenna. The term "radiation pattern" of the antenna is used here synonymously with the receiving pattern of the antenna. This interchange of terms is justified by the law of reciprocity, which states that the radiation and the reception patterns of a given antenna are identical.

The measurement of antenna radiation patterns is very complex, especially when the antenna system is intended for long-distance operation. Several restrictive problems must be overcome before actual transmitting conditions can be simulated. For example, the wave-front intercepted by the antenna to be tested must be essentially plane, and the phase relationship of the voltages induced in it must appear as though the wave had originated at a distance large compared

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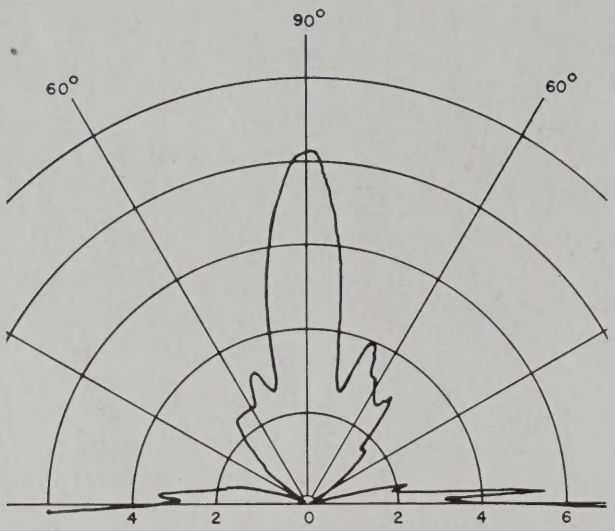

Power radiation pattern of a test antenna modeling performance of a 5-element yagi array that normally operates at about 50 Mc. The pattern was made on an automatic pattern-recorder located 200 feet from the model antenna range.

TECHNICAL NEWS BULLETIN

U. S. Department of Commerce

Charles Sawyer, *Secretary*

National Bureau of Standards

A. V. Astin, *Acting Director*

DECEMBER 1951 Issued Monthly Vol. 35, No. 12

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Subscription price, domestic, $1.00 a year; foreign, $1.35; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, February 3, 1950.

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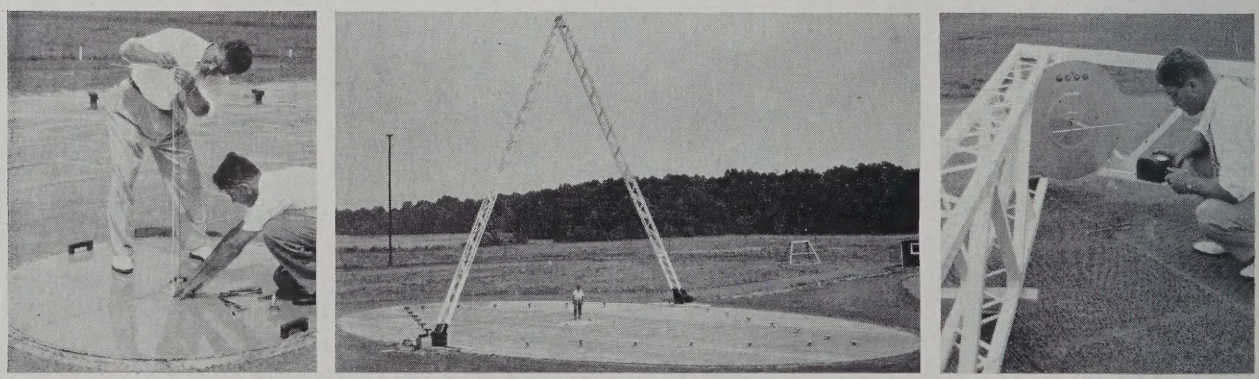
to the size of the antenna. Also, a separation of at least several wavelengths must exist between the target transmitter and the test antenna in order to minimize the surface wave component of the radiated field.

In recognition of these restrictions, a scaling factor of 60 ($n=60$) is employed in many of the applications. Thus a prototype frequency between 1 and 25 Mc is represented by model-transmitter frequencies between 60 and 1,500 Mc. At these frequencies, it is comparatively easy to arrange a model transmitting-receiving system so that it satisfies both of the previously mentioned limitations.

In addition to dividing the physical dimensions of the model by the scaling factor, n, and multiplying the frequency by the same factor, it is necessary to multiply the conductivity of the antenna and the ground by n. Fortunately, in most practical h-f antennas the copper losses are small, and the conductivity effects may be ignored without introducing any serious error. On the other hand, in considering ground conductivity, certain factors must be recognized: in a given location, the conductivity as well as the dielectric constant of the ground varies with weather conditions; and the ground constant varies from one geographical location to another. Consequently, it becomes necessary to specify a standard ground for certain operating conditions. Ideally, if different values of scaling factor are to be used, the material forming the ground plane of the model range should be changed so that its conductivity would be that of the standard ground



The NBS model antenna range is designed to measure antenna radiation patterns in the vertical plane. The inverted-V structure supports a self-contained target transmitter at the vertex (right) and can be moved in a 180° arc (90° position, center). The antenna to be tested (enlarged view, left) is placed at the center of an oval-shaped ground plane, composed of sheets of metal hardware cloth to simulate the ground effects of a salt marsh. Model techniques permit investigation of antenna characteristics in the 1-to-25-Mc region while actually operating at frequencies between 60 and 1,500 Mc.

corresponding to the new scaling factor. One type of ground that does not require a scaling factor is a perfectly reflecting surface. Communication sites located on salt marshes and over sea water have practically this type of ground. For the purpose of the model range, the problem of scaling the ground was, therefore, resolved by simulating a perfect ground by placing a ground covering consisting of a metal hardware cloth.

The target transmitter is supported by two open-truss beams, each 60 feet in length, fastened together at one end to form a 60° angle. The other two ends of the beams are mounted to two horizontal colinear axes located just high enough above the ground to permit a 180° movement of the structure. In the vertical position, the structure resembles a giant inverted V. The structure is counter-weighted so that it requires very little power to move it through its path. The target transmitter is fitted into the vertex of the inverted V, and the model antenna is located at the center of the ground plane.

The radio energy intercepted by the model antenna is rectified, and the signal voltage is transmitted along underground cables to a recording pen attached to an automatic pattern plotter. Synchrogenerators, connected to the axis of the V-frame, transmit its position to the turntable of the pattern plotter. Thus an automatic record of the radiation pattern is plotted as a function of the angular displacement of the transmitter moving above the antenna. All of the recording equipment is located in a shelter 200 feet from the antenna site.

A series of target transmitters that derive their operating power from small storage batteries within the unit are employed. This obviates the necessity of using connecting cables and wires that could reflect or otherwise disturb the radiated field. To prevent reflections that would be set up by a conducting material, the truss beams forming the V-frame are made of nonconducting hard plywood. Except at the base, all joints are sealed by synthetic resin glue; the structure is painted with white lead.

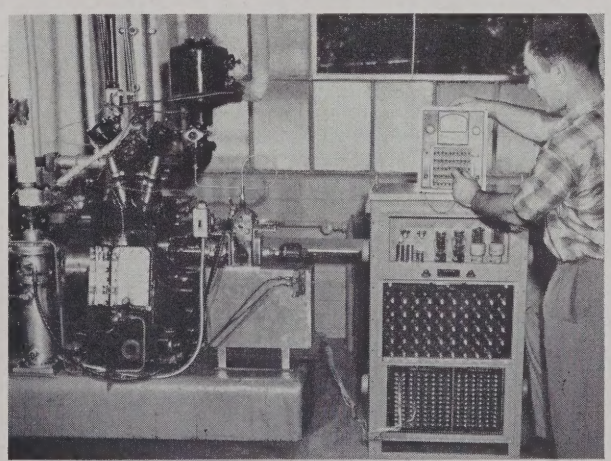
48-Point Temperature Monitor

A TEMPERATURE monitoring device, recently developed by M. L. Greenough, F. H. Bayhi, Jr., and Melvin Martens of the NBS electronic instrumentation laboratory, flashes a warning if the temperature at any one of 48 remote points rises above an individually predetermined safe value. Although the unit was developed to monitor temperature-critical points in shipboard applications, it could be used similarly in other types of installations.

From the centrally located NBS monitor unit, pairs of wires run to individual thermocouples mounted at the critical points. A master alarm light goes on if any of the 48 points becomes too hot, and an alarm bell will ring simultaneously if desired. The location of the trouble is shown promptly by a separate indicating unit. On the panel of this unit are 48 lights arranged in rows, each light corresponding to one of the 48 thermocouples. These lights go on to show which thermocouples (up to five) are overtemperature.

A crucial part of the NBS temperature monitor is its scanning switch. This is a mechanical assembly rotating uniformly with a 5-second period. On each revolution, one section of the switch samples each of the 48 thermocouples in turn. The thermocouple signal, after application of a voltage that automatically corrects for variations in the cold-junction temperature, passes through a pulse-forming circuit and is then amplified. The amplified pulses are fed to an alarm relay circuit, consisting essentially of a thyratron whose grid-to-cathode bias is arranged to be proportional to the desired alarm temperature. This bias arrangement is accomplished with the help of another section of the scanning switch; the required bias, individually adjustable, is inserted for each thermocouple at the time the thermocouple is switched in. Whenever the pulse amplitude exceeds the bias on the thyratron, the tube fires, closing a self-latching relay that turns on the master alarm light, and, optionally, rings the alarm bell.

The proper bias voltages for the single thyratron are supplied by 48 individually adjustable alarm level circuits. When the thyratron fires on an overheated thermocouple, the discharge current flows through the associated alarm level circuit. This causes an instantaneous voltage rise, which is transferred through coupling capacitors to the starter electrode of one of 48 cold-cathode tubes, causing the tube to discharge. The 48 overtemperature indicating lights are connected in the plate circuits of these tubes so that discharge of one of the tubes lights up the proper indicator, which remains lighted until reset.



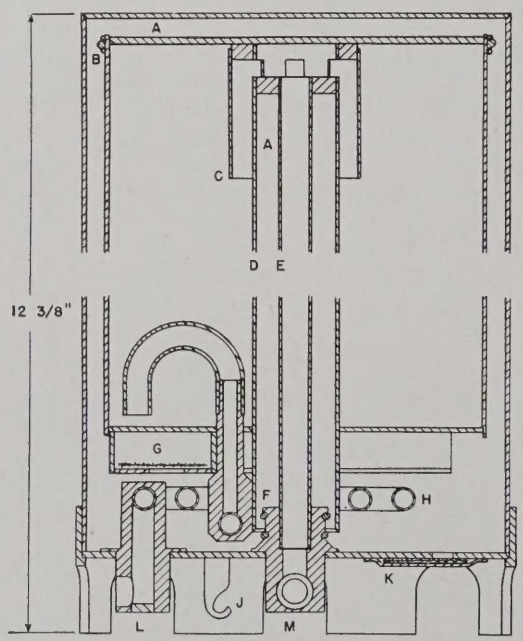
The NBS 48-point temperature monitor (right) gives an alarm—a light, a bell, or both—when the temperature at any of 48 remote points rises above a predetermined value. The set is connected experimentally to thermocouples mounted at critical points on a test engine.

Vacuum Flasks of Unusual Design

EXTREMELY compact vacuum flasks for the storage of cold liquids—such as liquid oxygen and nitrogen—have been designed by D. S. Goalwin and C. F. Eve of the Bureau for the U. S. Air Force. Although the flasks constructed at NBS have been of less than 2-liters capacity, they introduce several new features in Dewar-flask design that may well find application in large storage tanks. Two of the flasks also demonstrate the practicability of building invertible Dewars that have the same evaporation loss inverted as erect.

Laboratory flasks for storage of cold liquids are usually vacuum-insulated and are made in two common shapes: spherical with a long, thin neck, and cylindrical with a wide mouth. The spherical shape is used for storage where heat leak is to be kept to a minimum; the cylindrical type is preferred for cold traps and other experimental uses, where accessibility is of prime importance. Large spherical flasks are usually of copper and the wide-mouthed flasks of glass, although recently copper and stainless steel wide-mouthed flasks have become commercially available. In larger tanks, more design variety is evident; powder or fiber insulation is generally used in place of the vacuum, and the flask often takes the form of a cylinder lying on its side.

Recently NBS was requested by the Air Force to develop small liquid oxygen containers to supply breathing oxygen in fighter aircraft, where space is at a premium. Because the available space made a long, thin neck impractical, and because a sphere is an inefficient user of rectangular space, efforts were made to devise flasks of cylindrical shape having a long heat-conduction path between the cold liquid and the surrounding atmosphere. Three different types of cylindrical containers were designed and constructed.



A compact vacuum flask for the storage of cold liquids conserves space by using a long re-entrant neck (*E*), which doubles back through the liquid into the container. The neck is insulated by an extension of the vacuum space (*A*) within the outer neck, (*D*). Other features of the flask include: *B* and *F*, bumpers; *C*, filling level; *G*, charcoal sack (to aid in maintaining vacuum); *H*, bottom drain, serving also as liquid trap; *K*, safety release; *J*, *L*, *M*, vacuum, liquid, and gas connections.

One of these containers utilizes a re-entrant neck design. The neck doubles back into the container and through the liquid, insulated from it by an extension of the vacuum space, thus bringing both the gas and liquid connections out at the bottom of the flask. The minimum conductive heat path is along the neck, which is 11 inches in length and considerably longer in comparison to size than the outside necks on standard spherical flasks.

This container weighs 6.5 pounds and has a capacity of 1.75 liters. It is made of brass and evacuated to 0.5 microns; a sack of coconut charcoal helps to maintain this vacuum. The re-entrant neck is an inconel tube, 0.010 inch thick and 0.25 inch in diameter. The bottom drain is also of 0.010-inch inconel, is 0.25 inch in diameter, and acts as a liquid trap as well as a drain. The greater part of this tube fills with vapor, so that there is no short thermal path from the liquid surface to the outside. All joints are hard-soldered for added strength.

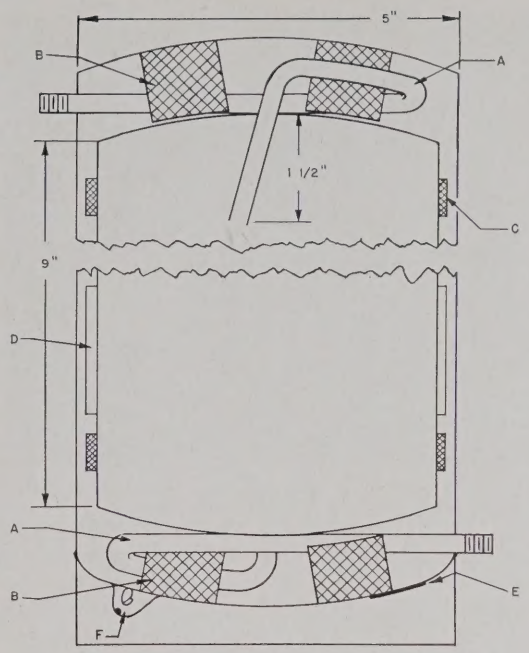
A second container fulfills a further military requirement in that it may be held upside down without increasing the heat leak. The entire inner chamber of the flask is supported within the outer case by two identical neck-drains. One, at the top of the flask, serves as a gas vent; the other, at the bottom, is used for adding liquid. When the flask is inverted, the roles of the two neck-drains become reversed. The flask is thus truly invertible, and may be held in any position except horizontal without materially increasing the heat leak.

The neck-drains of this flask are of stainless steel, 0.010-inch thick; each provides a longer heat conduction path than does the standard neck of the spherical flasks. The flask itself is of copper, and all joints are silver-soldered. Bumpers between the two walls of the flask prevent excessive movement of the inner flask with its resultant strain on the drain.

A third container is similar to the second, except that the top and bottom bumpers are placed in direct contact with the inner cylinder to prevent movement of this part of the container. As the bumpers are of glass cord, conically shaped, and are 2 inches long, the added heat leak is small—less than 10 percent of the total heat leak.

The evaporation rate of the first container, which employs the re-entrant neck, is 0.070 pound of liquid oxygen per hour; the flask thus loses its entire charge in 58 hours while standing. The second, invertible, container loses liquid oxygen at the rate of 0.065 pound per hour, corresponding to a loss of the entire

Invertible liquid oxygen flask of compact cylindrical design: The two neck-drains (*A*) are identical, the one at the top serving as a gas vent, while the one at the bottom is used for adding liquid. Bumpers (*B* and *C*) prevent excessive motion of the inner flask. A charcoal sack (*D*) aids in maintaining a vacuum and a blowout patch (*E*), soft-soldered to the container, permits the safe release of excess pressure if the vacuum is lost.



charge in 62 hours. The third container, with the contact bumper, loses an average of 0.073 pound of liquid oxygen in an hour, or its entire charge in 55 hours. These evaporation rates compare favorably with the loss rates of standard spherical containers with long necks. Larger flasks of these or similar designs would, of course, be more economical in that the percentage evaporation loss per hour would be less.

To determine the ability of the NBS containers to withstand rough usage, particularly in aircraft, they were subjected to both horizontal and vertical vibration with a double amplitude of 0.01 inch, at frequencies from 0 to 2,400 cycles per minute; no damage was observed. The flasks have been tested hydraulically to 200 pounds per inch at room temperature without damage, and have operated successfully while cold (−193° C) at 150 pounds per square inch.

Paper From Glass Fibers

PAPER composed entirely of glass fibers, with no additive, has been made for the first time at the National Bureau of Standards in cooperation with the Naval Research Laboratory. The all-glass paper—until now considered an impossibility—was developed by M. J. O'Leary, J. K. Missimer, J. J. Erving, and B. W. Scribner of NBS and T. D. Callinan and R. T. Lucas of NRL. The raw material, commercially available fine glass fibers, was mixed with water and formed into continuous sheets on the semicommercial paper-making machine in the NBS experimental paper mill. A number of special problems had to be solved, however, before a paper of satisfactory strength and characteristics was obtained.

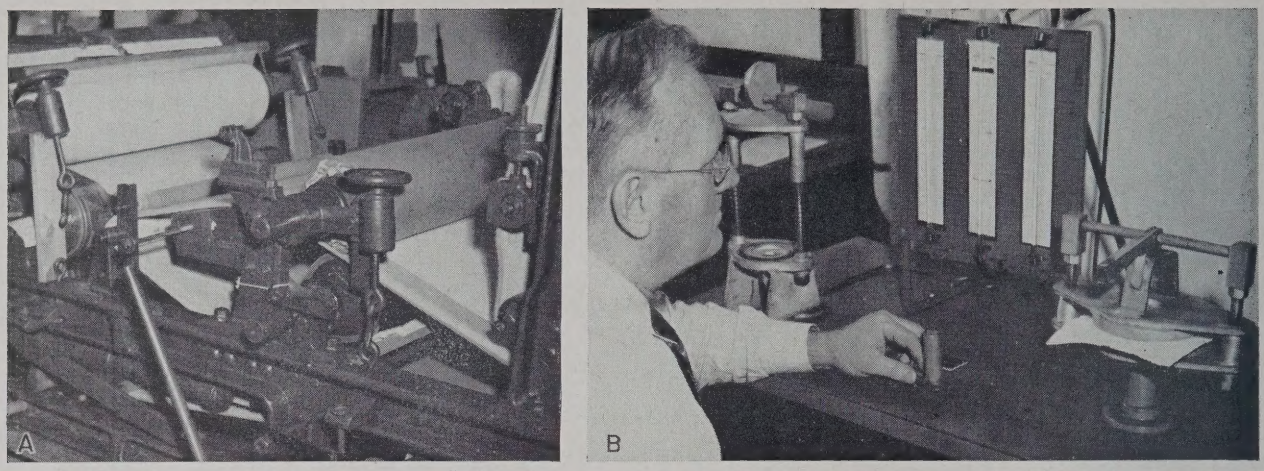
The all-glass paper has several important applications. As an air-filter paper, tests at NRL show the new paper to be many times more effective than present commercial filters. It seems particularly valuable for gas masks and respirators used by fire fighters, industrial and medical workers, and military personnel. In gas-mask tests in a smoke-filled room, only one smoke particle in 100,000 passed through the glass paper filter.

Another important advantage of the all-glass paper is its high resistance to effects of heat, moisture, chemicals, and micro-organisms. It has excellent electrical characteristics and should be valuable as an insulator and dielectric. For instance, it can be used to make oil-impregnated paper capacitors capable of operation even at temperatures above 200° C; suitable oils are available that withstand such temperatures, but the kraft paper commonly used is unsatisfactory for prolonged operation at temperatures much above 100° C.

In the manufacture of ordinary paper, vegetable fibers are processed with water in a "beater," which bruises the fibers and forms minute fibrillae. Prolonged beating reduces some of the cellulose to a gelatinous substance that cements the fibers together and strengthens the paper. With glass, on the other hand, bruising tends to weaken the paper, and no binding agent is formed.

To get maximum strength and optimum air resistance NBS experimented with different concentrations

The first paper ever made entirely of glass fibers has been produced at the National Bureau of Standards in cooperation with the Naval Research Laboratory. In the first step of the operation, bundles of commercial glass fiber are mixed with 99 parts of water in the beater.



(A) For good paper strength, crushing and breaking of the glass fibers must be prevented. NBS scientists found that use of a special soft-covered roll (right center) prevented weakening and pinholing, which occurred when the paper was run between metal rolls. (B) The air resistance of the all-glass paper is an important characteristic for air and gas filters. The new paper also promises wide practical value as an electrical insulator and dielectric.

and beating times. A 1-percent glass concentration in the glass-and-water beater stock gave a stronger paper than higher concentrations, but further dilution had no advantage. Short beating times—just long enough to separate the glass fibers—were best.

The glass-fiber-and-water stock was flowed onto a 29-inch Fourdrinier paper-making machine having a 70-mesh wire 33 feet in length. From the endless-belt wire screen the wet glass-paper sheet passed between special rollers, through driers, and onto a reel.

It was found that the wet paper could not be passed through metal rollers without weakening and pinholing. With a cushioning jacket on the first press roll, however, the wet paper was satisfactorily pressed against the felt surface under the paper with minimal injury to the fibers.

Commercial glass fibers of finest diameter—grades of 0.75 micron (about 30 millionths of an inch) or less in size—gave papers with the best strength and filtering characteristics. Other experiments indicate that the strength depends on the presence of fibers of assorted lengths, but that very short fibers weaken the paper if present in substantial quantities. A sample of the water-fiber mix from the beater was run through a pulp classifier having screens of 65, 100, 150, and 200 mesh. Hand sheets made from fibers retained by the 65-mesh screen had only about one-fourth the tensile strength of the original paper, and hand sheets made from the combination of the 100-, 150-, and 200-mesh fibers were even weaker. But when paper was made of a mixture of fibers from all 4 screens, its tensile strength was 10 times greater than that of the original paper. This remarkable increase in strength apparently resulted from the removal of the "fines" (or fillers)—the fibers that pass through the 200-mesh screen.

For further technical details of the electrical characteristics, see The electrical properties of glass-fiber paper, *by T. D. Callinan, R. T. Lucas, and R. C. Bowers, Elec. Mfg.* **48**, *94 (Aug. 1951).*

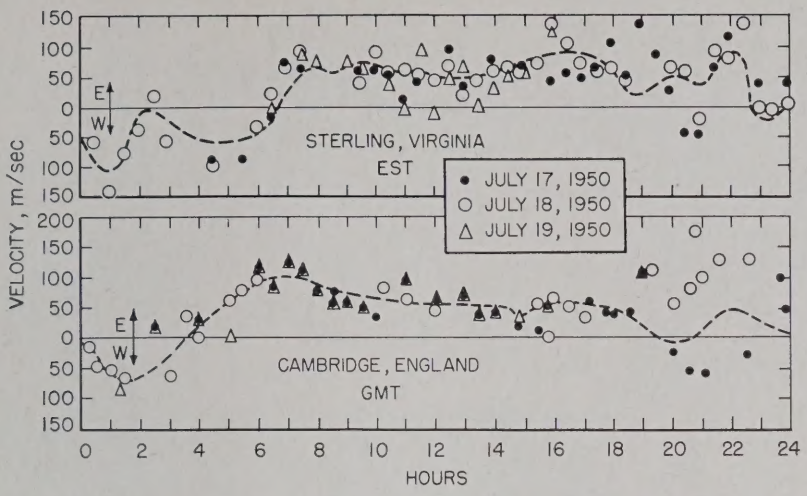
Winds in the Ionosphere

ONE of the causes of fading in radio communications is a wind phenomenon in the ionosphere that closely resembles surface winds. Winds of the upper atmosphere are produced by solar and lunar gravitational tides and by the heating effect of radiations from the sun. Because knowledge of these motions is necessary for correct evaluation of the role of ionization, deionization, and diffusion processes in the upper atmosphere, the Bureau has incorporated a study of winds in its ionospheric research program.

NBS observations of ionospheric winds are made on a regular monthly schedule, and the data are coordinated with similar observations made by scientists in Great Britain and in Canada. The good agreement that has been obtained between the records of the three participants suggests the possibility that the observed winds belong to a world-wide circulatory system of the outer atmosphere.

Analysis of the results indicates that the azimuths of the winds are subject to seasonal variations. During June, July, and August the winds blow principally to the east. In December, January, and February the wind direction is generally southwesterly. During the spring and fall, the winds often appear to rotate in a clockwise sense, completing two complete rotations in a 24-hour period. The wind speeds are also subject to variations; some are as high as 300 m/sec (660 mph), but the average is about 70 m/sec (150 mph).

In the past, ionospheric-wind characteristics have been calculated from observations of slowly drifting meteor trails and luminous clouds occasionally seen during the night hours. However, because the data are



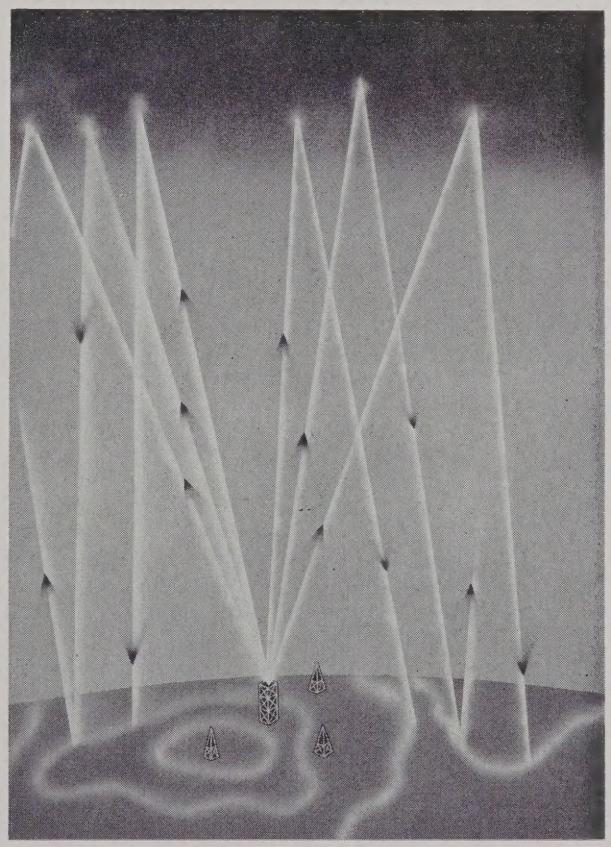
Comparison of winds-of-the-ionosphere data recorded at the NBS radio propagation field station at Sterling, Va., with those recorded at the Cavendish Laboratory propagation station at Cambridge, England. The data show good agreement between velocities of winds measured over the United States (upper) and over the British Isles (lower). This correlation indicates that the ionospheric winds belong to a world-wide circulatory system.

derived from relatively rare phenomena, this method is not capable of giving a comprehensive picture of upper atmosphere winds. At present the Central Radio Propagation Laboratory of NBS is using a systematic technique that takes advantage of the reflecting property of the ionized layers in the ionosphere.

When radio waves of constant amplitude are reflected from the ionosphere back to the earth, they usually return with an amplitude that varies erratically with time. The variation, or fading, of radio signal is generally a nuisance factor in long-distance communications but aptly lends itself to an investigation of ionospheric winds.

If the fading is observed at two receiving antennas separated by one or two wavelengths of the probing radio waves, the fading patterns are very similar, but often appear displaced in time. This time delay can be explained by assuming that the ionosphere is made up of patches of ionization; in other words, some parts of the ionosphere are more densely ionized than others. For this reason, the radio waves that are scattered or reflected from the ionosphere produce a diffraction pattern of signal intensities on the ground. Thus, as the overhead layer of the ionosphere moves, the ground pattern also moves, and the fading sequence appears first at one antenna and then the other. The amount of time delay between the arrival of various parts of the fading pattern at the two antennas will depend on the speed of the movement. The direction and speed of the motion can be determined by using three antennas located at the corners of a triangle and employing triangulation principles. The ground pattern moves twice as fast as the ionosphere irregularities that give rise to it.

The ionospheric-winds equipment is located at the NBS radio propagation field station at Sterling, Va. It consists of a transmitter operating at 2.3 Mc and three receiving antennas and their associated radio receivers. The transmitter produces 200-microsecond pulses with a peak power of 10 kilowatts at a rate of 60 a second. The receivers are gated to respond only to those pulses that have been singly reflected from the ionosphere (single-hop reflection).



Pictorial representation of the systematic technique used to study movements of winds in the ionosphere. A transmitter (center) sends out signals that are reflected back to earth by the ionized layers 100 km in the upper atmosphere. "Single-hop" reflections are detected by three receiving antennas surrounding the transmitter. The ionosphere, made up in part of patches of ionized matter, scatters and reflects the signals, producing a "diffraction pattern" of signal intensities at the ground (foreground). As the overhead layer moves, the ground pattern also moves, and the fading sequence appears first at one antenna and then the other. Three antennas are used to obtain direction and velocity by triangulation.

Research on Electrode
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Dr. William Blum, *who pi*
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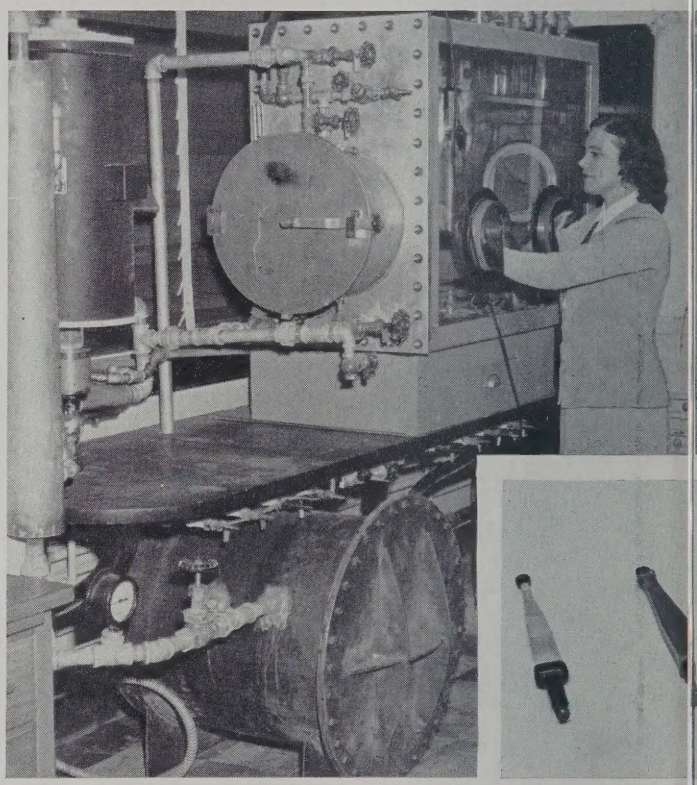
SINCE 1913 the National Bureau of Standards has been continuously engaged in a program of basic and applied research covering many phases of the general field of electrodeposition. The interest of the Bureau in this field was initiated primarily to meet the needs of the electrotyping industry, but was soon extended to include electroplating. Prior to that time these two industries were operated largely upon an empirical basis, with very little technical direction or control. However, they have been on a sound scientific basis now for many years, partly because of the pioneering research on methods and techniques at NBS.

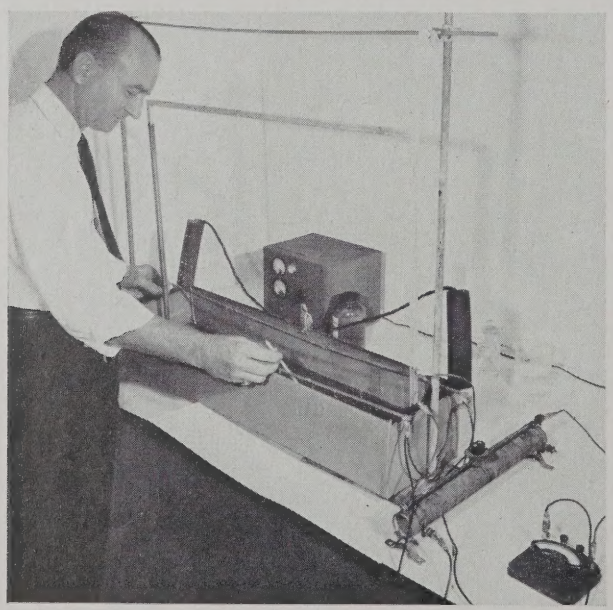
The principal industrial applications of electrodeposition fall into four fields, namely, electroplating, electroforming, electrorefining, and electrowinning. *Electroplating* involves the application of adherent metal coatings on a variety of articles to improve their appearance and resistance to corrosion. Numerous everyday uses are seen on automobiles, electrical and household appliances, and tableware. *Electroforming* is the production or reproduction of articles by electrodeposition. Its most widespread uses are the production of electrotypes for printing and of matrices for molding phonograph records. *Electrorefining* is used to convert impure metals, such as crude copper and nickel, into pure metals. *Electrowinning* involves the extraction of metals such as zinc from their ores, and the recovery of the pure metals by electrodeposition.

The electrodeposition studies at NBS, as explained earlier, have been directed chiefly toward the electroplating and electroforming industries, though some of the principles and methods may find application in the other two fields. The major directions in which the Bureau has sought to aid these industries are (1) developing methods for testing and controlling the solutions used and the resultant deposits, (2) definition of optimum conditions for the operation of existing processes, (3) development of new or improved processes, (4) specification and standardization of the deposited coatings, and (5) studies on principles of electrodeposition.

In these studies NBS has cooperated actively with other Government agencies, such as the Government Printing Office and the Bureau of Engraving and Printing in the production of printing plates; and with



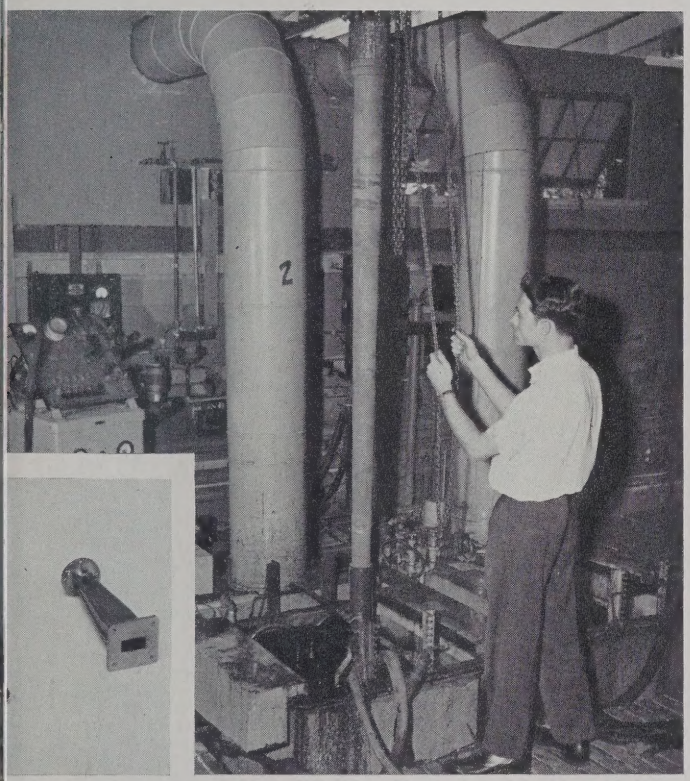
(Left) "Dry box" for preparing chemicals: In the preparation may be necessary to exclude moisture or oxygen. The dry bo nitrogen or other inert gas is recirculated continuously. The i ings. (Center) Electroformed waveguides: Electroforming of guides, in which the inside dimensions must be very accurate interior of gun bores: A 40 mm (1.6 inch) gun barrel with an



Gold-plating frames for the Constitution and the Declaration of Independence. The frames used in the new enclosures for these historic documents were made of bronze and plated with a thick gold coating that will ensure protection against corrosion for a long period.

osition at the National Standards

ared this report, is Assist-
try Division and Chief of
. Dr. Blum *will retire on*
42 years on the NBS staff.



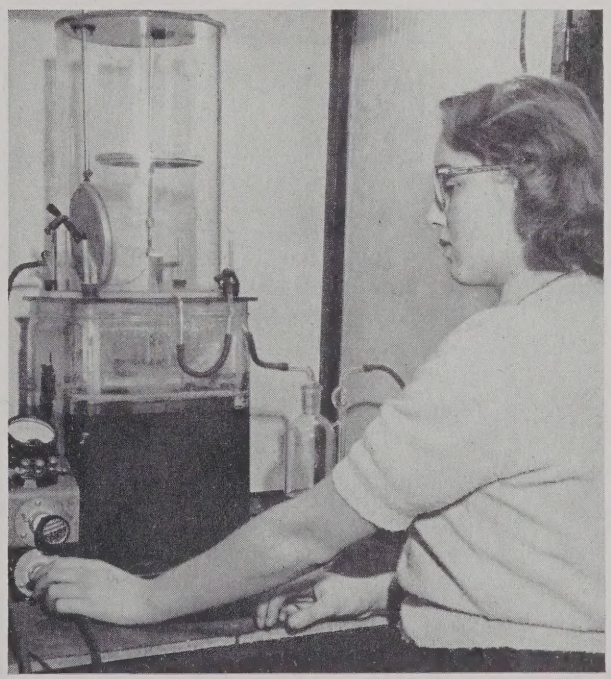
certain special compounds for electrodeposition research, it is so constructed that a stream of dry air, or of oxygen-free aratus in the box may be manipulated through gloved open- pper or other metals is the best method of producing wave- controlled. (Right) Apparatus for plating chromium on the ide anode is being lowered into the chromium plating bath.

the Departments of the Army and Navy in the applications of electroplating not only to guns and armament, but also to the vast array of equipment used by the Armed Services. This work for the Defense Establishment was most active during World Wars I and II, but was also continued in the interval and since World War II. In addition these studies have been closely associated with the International Association of Electrotypers and Stereotypers, the American Electroplaters' Society, and the American Society for Testing Materials. Over 150 papers on electrodeposition have been published by the Bureau, and numerous Federal and ASTM Specifications are based in part on the results of NBS research.

Printing Plates

As a result of studies conducted in cooperation with the Government Printing Office and the Royal Electrotype Co. of Philadelphia, favorable conditions for making copper and nickel electrotypes were defined, and simple methods of analyzing the solutions were developed. The properties of graphite used in electrotyping were specified. The magnitude and source of changes in dimension that may occur in making electrotype plates were defined. The net result of these studies and of others that were stimulated by these researches was to place the electrotyping industry on a much more scientific basis than in its earlier years.

In 1920 NBS was requested by the Bureau of Engraving and Printing to assist in developing an electrolytic process for reproducing the plates used to print currency. The first requisite was that the process must be very accurate, in order to insure that the millions of notes of a given denomination be absolutely identical. This requirement was met in the electrolytic process installed there in 1920 and employed and improved since then with the continued cooperation of NBS. By plating chromium on the surface of the electrolytic currency plates, and also on the steel plates used for printing postage stamps, the useful life of these plates was increased many fold.



Laboratory apparatus for electrodepositing aluminum. A new type of organic bath that contains lithium hydride was developed for depositing aluminum. In order to avoid introducton of moisture, the bath is covered with a container through which dry air is passed.

This process has yielded an improvement in the quality of the printing and a marked decrease in its cost.

Chromium Plating

The National Bureau of Standards took an active part in the development of chromium plating and early defined favorable conditions for its deposition. Chromium plating of printing plates, started in 1924, was one of the earliest industrial applications of this process. During the past few years NBS has made a detailed study of the physical properties of electrodeposited chromium, which has assisted the industry in defining conditions for plating chromium to meet specific conditions of service.

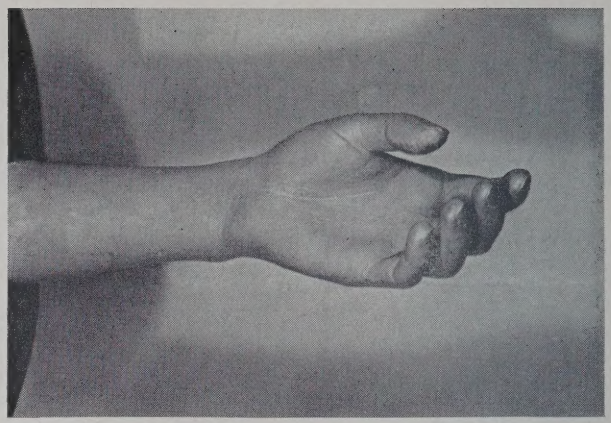
The extreme hardness of chromium soon led to its application by both the Army and Navy to the surface of gun bores, thus increasing their resistance to abrasion and erosion. Extensive studies, still in progress, have been conducted in cooperation with the Army and Navy to define the optimum thickness of chromium, as well as methods of preparation and plating for each type of weapon and service. As a result of these and other studies, the life of small caliber gun barrels has been increased several fold, and that of larger guns has been doubled. Chromium is not the ideal substance for gun bores, but it is the best metal coating thus far applied on a large scale.

In an effort to determine the mechanism of chromium plating from the chromic acid bath, some interesting experiments were carried out with solutions containing radioactive chromium-51. By measuring the radioactivity of the chromium deposit, it was demonstrated that chromium is deposited directly from the chromic acid (hexavalent chromium) and not from the trivalent chromium that is produced in the bath by partial reduction of the chromic acid.

Nickel Deposition

Most nickel plating is conducted from slightly acid solutions. In 1922 NBS showed that indicators may be used to measure, in terms of pH, the acidity of the baths and thus permit their more uniform operation. Later, these pH measurements were made with the quinhydrone electrode, and at present are being made with the glass electrode. Thereby the control of the most important single factor in nickel deposition was changed from guesswork to science.

In subsequent years the Bureau has made numerous studies on nickel baths to measure their conductivity, polarization, and throwing power, and to determine the effects of impurities on the deposits. The electrodeposition laboratory of the Bureau has just completed, in cooperation with the American Electroplaters' Society, a comprehensive research on the physical properties of electrodeposited nickel. The results show that by varying the bath composition and pH, the temperature, and the current density, it is possible to produce nickel deposits with Vickers hardness from 150 to 750, and tensile strengths from 40,000 to 200,000 pounds per square inch. These and previous studies



Electroformed nickel mold used for making plastic gloves for artificial hands. Developed by NBS in cooperation with the Prosthetics Research Laboratory of the Army Medical Center.

reveal also that the properties of deposits of nickel and chromium are closely related to the content of oxygen, hydrogen, or other elements (usually a small fraction of 1 percent). Much more work is required to determine the source, form, and location of these inclusions in electrodeposits.

A process known as electroless plating has been developed by which nickel or cobalt may be deposited by the use of a reducing agent, such as sodium hypophosphite. This process is finding industrial and military applications on the interior surfaces of small tubes and on other areas where it is not practicable to use an anode.

As the electroless nickel deposits contain phosphorus and are relatively hard, a study was made of the possible codeposition of nickel or cobalt with phosphorus. It was found possible to deposit as much as 10 percent of phosphorus, producing fairly hard alloys that can be made still harder by a suitable heat treatment. The cobalt-phosphorus alloy has been successfully applied in the electroforming of precision dies, in which metals such as copper are formed by pressing.

Specifications and Testing of Plated Coatings

The Bureau has cooperated since 1932 with the American Electroplaters' Society in exposure tests of plated coatings, which are still in progress. Specimens plated with coatings of carefully controlled thickness were exposed at industrial, marine, and suburban locations, and inspected at intervals. From the periods required for rust or other failures to appear, the relative protective values of typical coatings were determined.

From the results of these tests and of general experience, type specifications for plated coatings were prepared and were adopted by the American Electroplaters' Society and the American Society for Testing Materials. Similar requirements have been incorporated in Federal Specifications for plated coatings on articles purchased by the Government.

Because the minimum thickness of plated coatings is one of the most important factors in their useful life, rapid and reliable methods for measuring the local thickness of coatings are desirable. Nondestructive methods are preferable because they permit the testing of a larger number of samples.

The Bureau therefore developed nondestructive magnetic methods for measuring the coating thickness, provided that either the coating or the basis metal is magnetic. These methods are employed in an instrument known as the Magne-gage, which was designed at NBS but is manufactured commercially. Each Magne-gage is calibrated at NBS before it is sold. Over 4,000 are now used for testing coatings on industrial, household, and military equipment. The principle has also been used in gages for measuring the thickness of chromium inside gun barrels.

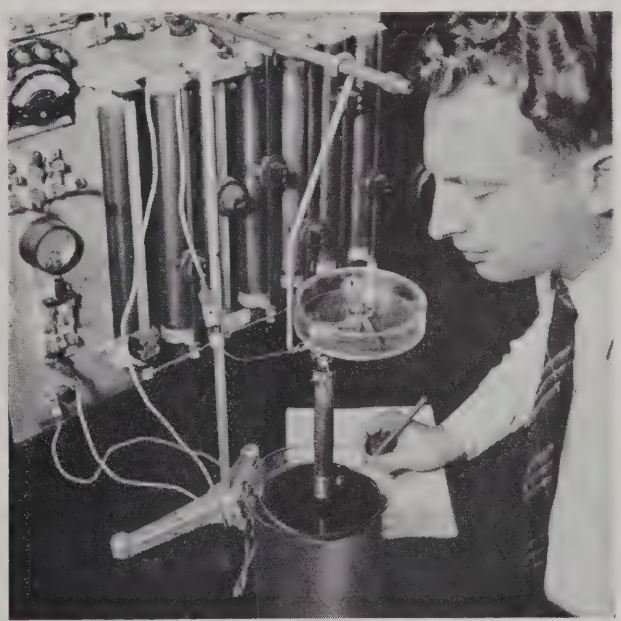
A further important requirement of a plated coating is good adherence; otherwise it may peel or blister and permit corrosion to occur. Methods for measuring the adhesion of coatings have required the preparation of special specimens. In the "nodule" method recently developed at the Bureau, however, a small mushroom-shaped nodule is plated adherently to the external surface of the coating whose adhesion is to be measured. The force necessary to detach the small area of coating under the nodule is then a measure of its adhesion. Although the method has not yet come into extensive use, it is a promising acceptance test for adhesion.

Still another property of coatings that may affect their usefulness is the stress that may develop in a coating during its deposition. If this stress is high, the coating is likely to crack in service. An instrument known as a spiral contractometer was devised at NBS to measure the stress during deposition. When metal is deposited on a spiral strip, any contractile stress causes movement of a needle that is geared to the lower free end of the spiral. From the extent of this movement, the stress (for example, in pounds per square inch) can be readily computed. Measurements with this instrument might well serve to show the presence of impurities that increase the stress, and thus permit better control of the baths.

One of the most critical properties of electrodeposits used to resist wear or abrasion, on printing plates for example, is hardness. Many measurements of the hardness of deposits of nickel and chromium have necessarily been made in NBS researches. When the coatings are subjected in service to high temperatures, as in gun barrels and jet engines, their hardness at elevated temperatures, known as hot-hardness, is important. Methods and equipment for measuring the hot-hardness of metal coatings were therefore developed at NBS.

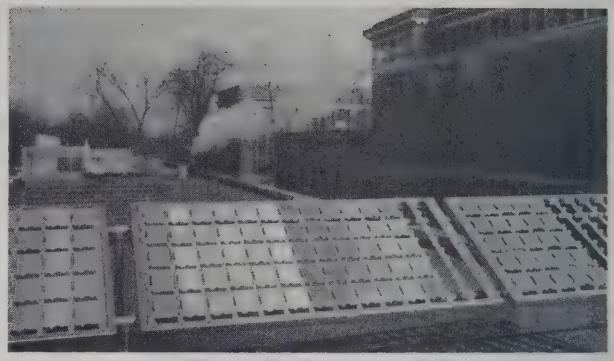
Electrodeposition from Nonaqueous Solutions

Inspection of the periodic system of the elements shows that about 33 metals, all in one rectangular block, can be electrodeposited from aqueous solutions. These include about 15 metals that are electrodeposited commercially, such as copper, silver, gold, zinc, cadmium, indium, tin, lead, chromium, iron, cobalt, nickel, platinum, palladium, and rhodium.



(Left) Magne-gage for measuring the thickness of electroplated coatings by determining the force necessary to detach the magnet from the plated surface. The instruments are manufactured commercially and calibrated at NBS. Over 4,000 are now in use to test coatings on military and civilian supplies. (Right) Internal stress in electrodeposited coatings may be conveniently and accurately determined by means of the spiral contractometer. Compression or tension in a specimen coating deposited on a helix is indicated by the pointer of a dial as the helix changes curvature.

Exposure tests of plated coatings. Extensive exposure tests of electroplated metals were conducted in industrial, marine, and rural locations. The results were utilized in specifications for electroplated coatings that are employed by the Government and industry.



Adjacent to these metals are those such as tungsten and molybdenum, which cannot be deposited in a pure state from aqueous solutions, but can be deposited as alloys with iron, nickel, or cobalt. Studies made at the Bureau have defined conditions for depositing alloys of tungsten that are hard and have certain industrial applications.

There is a present demand for pure coatings of such metals as molybdenum, tungsten, titanium, zirconium, beryllium, and aluminum. If these metals can be electrodeposited in a pure form with good physical properties, such coatings will undoubtedly find important industrial and military uses. An intensive research program on this subject is in progress at NBS. Because it is very improbable that deposition of these metals can be accomplished from aqueous solutions, even under conditions of very high temperature and pressure, an investigation of which was carried out in NBS laboratories, studies are now being made on nonaqueous baths. These are of two types: those in which suitable metallic salts are dissolved in organic solvents to yield conducting solutions; and fused salt baths, usually operated at relatively high temperatures.

As an example of the possibilities in this extensive and difficult research field, a report has just been published describing a new type of organic bath for depositing aluminum. The bath consists of aluminum chloride dissolved in ordinary ether and contains also lithium or aluminum hydride. The presence of the hydride leads to production of dense, ductile deposits of aluminum, which will probably find use in plating other metals with aluminum and in electroforming wave guides for radio communication. It remains to be seen whether analogous baths may prove suitable for depositing other metals.

Typical of the fused salt bath is the cryolite bath containing dissolved aluminum oxide and universally employed for production of aluminum from bauxite. As the temperature of operation of this bath is above the melting point of aluminum, the latter is produced in a liquid form that is not suitable for coating metals or for electroforming of objects. The NBS search is devoted to baths that will yield solid metals, preferably in a dense form with a desired hardness and strength.

Research in progress on molybdenum deposition shows that fairly dense, pure deposits of molybdenum may be obtained from a fused bath operated at 600° C. Further work is required to define the optimum bath composition and operating conditions.

Studies of this character on the rare or unusual metals usually involve the preparation and purification of new compounds of these metals and the selection of suitable organic solvents or fused salts. Hence a large amount of preparatory work is required, one result of which may be the discovery of previously unreported compounds. Work under way here and elsewhere will undoubtedly lead to progress in this field, which has previously not been studied intensively.

Principles of Electrodeposition

The NBS studies and those conducted in other laboratories show that ultimate progress in the field of electrodeposition depends upon the acquisition of more knowledge regarding the mechanism of the process. This in turn must rest on a fuller knowledge of the atomic, molecular, and crystal structure of matter, and a better understanding of the constitution and behavior of the concentrated solutions used in industrial electrolysis. It is manifestly impossible to include in a narrow field such as electrodeposition, studies on these basic aspects of science. An effort has been made, however, at the Bureau to develop methods for measuring and expressing the general phenomena of electrodeposition and to correlate existing knowledge on specific problems with basic science.

One of the most characteristic and important features of electrodeposition is the polarization, that is, the change in potential, that occurs at the anode and cathode during electrolysis. This and the related overvoltage of hydrogen or oxygen have large effects upon the electrode efficiencies and the structure of the deposits. A simple method of measuring polarization was developed in the Bureau's early work and has proved to be a useful tool in research.

One of the practical problems in electrodeposition is the throwing power, which is an expression for the metal distribution on a cathode of irregular shape. A simple method was developed for measuring the throwing power under certain conventional assumptions, and this has found wide application in research on plating baths. In this connection the relations between throwing power and the primary current distribution, polarization, resistivity, and cathode efficiency were demonstrated.

Extensive studies have been made on the primary current distribution, which is determined solely by the geometry of the system. Methods of computing the distribution on eccentric cylinders, angles, planes, and other irregular surfaces were developed.

The actual electrode processes take place within a very thin film of solution adjacent to the electrodes. This film differs in composition from the body of the

solution. Therefore, methods of studying the composition of cathode films were investigated. It was found that by conducting the deposition on the outside of a cylinder into which a low-temperature freezing mixture could be quickly introduced, the adjacent film was thereby instantaneously frozen. While keeping it cold, successive layers of the frozen film were turned off on a lathe and were analyzed. The results made it possible to plot the concentration gradients within a hundredth of an inch of the cathode surface.

Future Program

Much more extensive studies are required to understand electrodeposition. These will be conducted as rapidly as the scientific program of the Bureau permits. It is difficult to make plans for research long in advance, especially in the present unsettled state of world affairs. Even though, as now seems apparent, research in this and other fields is guided largely by present or prospective military needs, the latter involve such wide possibilities that research on all phases of electrodeposition is warranted. It is safe to say that the most promising field for study is nonaqueous solutions. Success in this field may well lead to or make possible important industrial and military developments. Special efforts will be made to concentrate work on this subject.

The same uncertainty is reflected in industrial electroplating. For example, the very great increase in the amount of nickel used in alloys for jet engines and other equipment has curtailed nickel plating on automobiles and other equipment. Substitutes now used, such as the plating of chromium over copper on steel, followed by a coating of clear lacquer, are not as satisfactory as the copper plus nickel plus chromium coatings normally used on steel. Any substitutes employing metals that are more available than nickel will be welcomed by the plating industry. Further studies on other metal and alloy coatings are therefore warranted, including their behavior in the atmosphere and in service.

Experience in World War II has shown that even though plating for civilian use was sharply curtailed, the military needs required a total amount of electroplating that exceeded normal production. It therefore seems likely that uses of electroplating will increase, and that demands for research in this field will continue to expand.

Symposium on Electrochemical Constants

Over 170 leading chemists from this country and abroad attended the NBS Semicentennial Symposium on Electrochemical Constants, held at the National Bureau of Standards in Washington, D. C., September 19 to 21, 1951. The symposium was held as part of the scientific program honoring the fiftieth anniversary of the Bureau's establishment. More than 30 papers were presented by representatives of industry, Government, and the universities. Among the topics considered were the faraday constant, standard cells, transport numbers, electrolytes, conductivity, polarography, electrode potentials, and kinetics. Sponsored by NBS in cooperation with the Office of Naval Research, the program was under the chairmanship of Dr. Walter J. Hamer, chief of the NBS electrochemistry laboratory.

In recent years renewed interest has been shown in the value of the faraday constant, and this problem received major emphasis at the symposium. For over 30 years, the discrepancy between the values obtained by the silver and iodine coulometers has been of concern. The question of inclusions in the silver of the silver coulometer was reviewed by Dr. A. F. Scott (Reed College), who also described some recent experiments in which radioactive tracers were used to estimate the magnitude of errors arising due to occlusions in the silver. Drs. D. N. Craig and J. I. Hoffman (NBS) described a new electrochemical method for the determination of the faraday that is free of isotope effects and occlusion errors. This method involves the anodic oxidation of oxalate ion. Drs. H. Sommer and J. A. Hipple (NBS) discussed the first determination of the faraday by a strictly physical method that employs an instrument known as the omegatron. By this method, the faraday is evaluated in terms of the ratio of the magnetic moment to the angular momentum of the proton and the ratio of the spin precessional frequency of the proton to the cyclotron resonance frequency of an ion whose isotopic weight is known.

The electrolytic conductivity of electrolytes at dilutions heretofore not precisely studied was described by Dr. E. G. Baker and Professor C. A. Kraus (Brown University). From measurements of the conductance of electrolytes in mixed solvents, Drs. R. C. Miller and R. M. Fuoss of Yale University presented evidence which indicates that the properties of such solutions depend on the sequence in which the solutions are prepared. High field conductance (Wein effect) was discussed for some paraffin chain electrolytes by Dr. Samuel Gusman (Rohm and Haas Research Laboratories).

Several papers dealt with transport numbers. Dr. D. A. MacInnes and Dr. Margaret O. Dayhoff (Rockefeller Institute for Medical Research) described a new method for the determination of transference numbers using an emf-centrifuge. Professor A. R. Gordon and Dr. R. L. Kay (University of Toronto) discussed the general theory of moving boundary measurements and described a moving boundary technique whereby true values of transference numbers can be obtained even if initial indicator concentrations are only one-fifth of the theoretical Kohlrausch value. Dr. L. G. Longsworth (Rockefeller Institute for Medical Research) described the separation of salt mixtures by moving boundary experiments in "unpacked" channels. Dr. R. A. Robinson (University of Malaya) reviewed a paper on "The analytical boundary method for the determination of transport numbers" by M. Spiro and

H. N. Parton of Canterbury University College, Christchurch, New Zealand.

For many years, chemists have sought an accurate method for the measurement of diffusion coefficients of electrolytes in dilute solutions. Professor Herbert S. Harned (Yale University) discussed a new method for the measurement of diffusion coefficients, and Dr. H. J. V. Tyrrell (Sheffield University, Sheffield, England) reported on some of his recent work on thermal cells, or cells with temperature gradients, a subject given little attention at the present time in this country. Dr. Otto H. Müller (Syracuse University Medical Center) pointed out that no agreement has yet been reached on the numerical values of the Ilkovic equation for the diffusion current in polarographic studies.

The stability and reliability of standard cells of the unsaturated and saturated type were treated in three papers. Dr. Marion Eppley and G. D. Vincent (Eppley Laboratory, Inc.) presented a complete and comprehensive study of the effect of septa on the performance of portable standard cells. F. X. Lamb (Weston Electrical Instrument Corp.) released for the first time data on the stability of Weston standard cells. Dr. W. J. Hamer, Langhorne H. Brickwedde, and Phyllis R. Robb (NBS) outlined the methods used by the National Bureau of Standards to maintain standards of electromotive force and compared the United States standard with those of other national standardizing laboratories.

Four papers were given in the field of electrode potentials and potential diagrams. Dr. H. D. Crockford (University of North Carolina) described measurements on the potential of silver–silver-chloride electrodes in aqueous-nonaqueous solutions. The factors involved in determining absolute electrode potentials were discussed by Dr. R. E. Wood (George Washington University). Dr. Herbert B. Callen (University of Pennsylvania) gave a masterful presentation of thermoelectric and thermomagnetic effects within the framework of irreversible thermodynamics. Professor Wendell M. Latimer (University of California) discussed the value of potential diagrams in the interpretation of inorganic chemistry.

The properties of electrolytes were thoroughly treated. Activity coefficients were discussed by Dr. R. A. Robinson (University of Malaya), effects of high pressures on electrolytic solutions by Dr. B. B. Owen (Yale University), and the problem of dilute solutions of strong electrolytes by Dr. George Scatchard (MIT). Professor W. F. K. Wynne-Jones (University of Durham, Newcastle-upon-Tyne, England), presented a paper on the significance of ionization constants, and Professor D. I. Hitchcock (Yale University) discussed standardization of the pH scale.

Four papers were devoted to the phenomena that occur at electrode surfaces. Dr. J. O'M. Bockris (Imperial College of Science and Technology, London) described experiments done in his laboratory to elucidate these complicated processes and Dr. A. L. Ferguson (University of Michigan) reviewed the various theories of overvoltage and discussed at length "transfer resistance." Dr. J. Th. G. Overbeek (van't Hoff Laboratory, University of Utrecht, The Netherlands) spoke on the significance of constants involved in electrochemical double layers. Dr. T. P. May and F. L. La Que (International Nickel Co.) gave the results of extensive studies done at the Marine Corrosion Laboratory at Harbor Island, N. C., on the corrosion of mild steel in sea water. Electrochemical constants involved in the general field of electrokinetics were discussed by Drs. A. J. Rutgers and M. DeSmet (University of Ghent, Ghent, Belgium). Their discussion included the results obtained in their laboratory over the past 15 years. Dr. Theodore Shedlovsky (Rockefeller Institute for Medical Research) presented a novel scheme to explain the source of electromotive force in systems free of metallic conductors. This concept, involving proton-protode exchange instead of the more familiar electron-electrode exchange, is of great importance in explaining energy precursors for bio-electric phenomena.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **47**, number 5, November 1951 (RP2259 to RP2267, incl.).

Technical News Bulletin, volume **35**, number 11, November 1951. 10 cents.

CRPL–D87. Basic Radio Propagation Predictions for February 1952. Three months in advance. Issued November 1951. 10 cents.

Research Papers

Reprints from Journal of Research, volume **47**, *No. 4, October 1951.*

RP2246. Spectrochemical analysis of bronze by a porous electrode method. Bourdon F. Scribner and John C. Ballinger.

RP2247. Correcting for density and viscosity of incompressible fluids in float-type flowmeters. Montgomery R. Shafer, Ernest F. Fiock, Harry L. Bovey, and Ross B. Van Lone.

RP2248. Mutarotation, hydrolysis, and structure of D-galactosylamines. Harriet L. Frush and Horace S. Isbell.

RP2249. The near infrared absorption spectra of deuterated acetylene. Earl K. Plyler and Norman Gailar.

RP2250. Spectrophotometric determination of bismuth in lead-base and tin-base alloys. Bruce T. Bendigo, Rosemond K. Bell, and Harry A. Bright.

RP2251. Calorimetric properties of benzoic acid from 0° to 410° K. George T. Furukawa, Robert E. McCoskey, and Gerard J. King.

RP2252. Infrared emission spectrum of calcium. Curtis J. Humphreys.

RP2253. Crystallization of aluminum chloride in the hydrochloric acid process for production of alumina from clay. Lewis Jesse Clark, Willard D. Hubbard, and James I. Hoffman.

RP2254. Creep of annealed and cold-drawn high-purity copper. William D. Jenkins and Thomas G. Digges.

RP2255. Tables of the functions $\int_0^{\phi} \sin \tfrac{1}{3} x \, dx$ and $(4/3) \sin -\tfrac{4}{3} \phi \int_0^{\phi} \sin \tfrac{1}{3} x \, dx$. Milton Abramowitz.

RP2256. Separation of close eigenvalues of a real symmetric matrix. J. B. Rosser, C. Lanczos, M. R. Hestenes, and W. Karush.

RP2257. Viscosity of dilute and moderately concentrated polymer solutions. S. G. Weissberg, Robert Simha, and S. Rothman.

RP2258. An analysis of the effect of the discontinuity in a bifurcated circular guide upon plane longitudinal waves. Louis L. Bailin.

Building Materials and Structures Reports

BMS126. Self-siphonage of fixture traps. John L. French and Herbert N. Eaton. 20 cents.

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C511. Hydrogen embrittlement of steel. Review of the literature. R. W. Buzzard and H. E. Cleaves. 20 cents.

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A proposed training program. W. S. Bussey. Scale J. (1703 East Eighty-fourth Street, Chicago 17, Ill.) **37,** No. 7, 4 (April 1951).

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The thermal hydrogen-oxygen reaction at relatively low temperatures. H. P. Broida and O. Oldenberg. J. Chem. Phys. (57 East Fifty-fifth Street, New York 22, N. Y.) **19,** 196 (February 1951).

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Relaxation and step-by-step methods. L. Fox. Math. Tables and Other Aids to Computation (2101 Constitution Avenue NW., Washington 25, D. C.), **5,** 92 (April 1951).

Elimination of randomization in certain statistical decision procedures and zero-sum two-person games. A. Dvoretzky, A. Wald, and J. Wolfowitz. Ann. Math. Stat. (Mt. Royal and Guilford Aves., Baltimore 2, Md.) **22,** 1 (March 1951).

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U. S. GOVERNMENT PRINTING OFFICE: 1951